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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c)

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INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	RESIDENCE (City and either State or Foreign Country)
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_____ Additional inventors are being named on the _____ separately numbered sheets attached hereto

TITLE OF THE INVENTION (280 characters max)

SYSTEMS AND METHODS FOR NON-CONTACT MEASURING SPUTTERING TARGET THICKNESS USING ULTRASONICS

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ENCLOSED APPLICATION PARTS (check all that apply)

- [X] Specification   Number of Pages __17__
- [X] Drawings   Number of Sheets __4__
- [ ] Application Data Sheet. See 37 CFR 1.76

- [ ] CD(s), Number
- [ ] Other (specify) _____

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_____ Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

SIGNATURE _Bruce E. Peacock_   Date:

TYPED or PRINTED NAME _Bruce E. Peacock_

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

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Invention:

SYSTEMS AND METHODS FOR NON-CONTACT MEASURING SPUTTERING TARGET THICKNESS USING ULTRASONICS

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SYSTEMS AND METHODS FOR NON-CONTACT MEASURING SPUTTERING TARGET THICKNESS USING ULTRASONICS

BACKGROUND OF THE INVENTION

Field of Invention

[0001] This invention relates to non-contact ultrasonic thickness measurement of sputtering targets bonded to a backing plate using immersion bubbler technique and data acquisition over-sampling.

Description of Related Art

[0002] In the fabrication of integrated circuits and other electronic, opto-electronic, microwave, and MEM devices, multiple deposition and etch processes are performed in sequence to fabricate the desired electronic structures or devices. The current trend in fabrication has been to improve the performance and reliability of devices with simultaneous reduction in manufacturing cost. The ultimate goal is to fabricate devices in a way that combines improved performance (speed and capacity), with improved cost efficiency of manufacturing process. Manufacturing cost can be kept under control in a number of ways, particularly by reducing the cost of consumables used in the process. One of such consumables is a sputtering target. The cost of the sputtering target can be reduced substantially by replacing the part of expensive target material which is not a part of the sputter erosion process, with less expensive commercially available "backing" material. The "backing" material, in addition to cost reduction, provides improved mechanical, thermal, and even electrical properties of the target. This becomes of particular importance for targets made of mechanically soft materials. These targets can be deformed by thermo-mechanical stresses applied to the target during sputter-related heat load cycling. In contrast, a backing plate made of "backing" material provides extra mechanical stiffness and improved thermal conductance.

[0003] Backing material can be attached to the target in a number of ways. However, only three techniques, namely, mechanical, diffusion, or solder bonding, are of practical interest for target-to-backing plate joining. All three techniques

require high or elevated pressure and high or elevated temperature to complete the bonding process. The drawback of these techniques is the significant difficulty in maintaining the pre-designed shape of the bond interface, for example, the flatness for planar targets. In many cases, when different target and "backing" materials are used, mismatches in thermal expansion coefficients of the different materials causes the bond interface to deflect from an originally predefined shape. The mechanical flattening which usually follows the bonding process is thus not always capable of flattening the bond interface to a satisfactory level. Therefore, in many cases only a partial correction of deflection of bonded interface is achieved that results in target thickness variations all over the target after sputter surface machining. The thickness variations, in turn, require close monitoring and measuring. Failure to determine the target minimum thickness may result in catastrophic performance of the target when the target sputters through the bond interface into the backing plate, causing contamination in sputtered films.

[0004] Attempts to use designing means to change the shape of pre-bonded surfaces to compensate for bonding-related deflection has shown mixed results. On the other hand, modeling, for example, by using finite element analyses, does not provide a satisfactory prediction for bond interface deflection due to many uncontrolled variables, which are typically not accounted for during analysis.

[0005] Therefore, there is still a need to measure the actual thickness of the target between front surface and the bonded interface. The conventional technique for thickness measurements of bonded assemblies is the ultrasonic NDT. A number of portable and stationary thickness measurement instruments or gauges are available from many NDT equipment manufacturers. The typical ultrasonic thickness gauge comprises an ultrasonic piezoelectric transducer electrically connected to an electronic block comprising, in turn, a pulser, a receiver, and a signal processor, which are controlled by the gauge's internal microcontroller.

[0006] The transducer, when excited by a short electric pulse from the pulser, generates a burst of high frequency mechanical vibrations or sound waves. This sound burst or pulse propagates through the specimen if the specimen is ultrasonically coupled to the transducer. The sound pulse, when it reaches the

bond interface, bounces back to the transducer in the form of an echo. The transducer converts the echo back into an electric signal. The electric signal is processed by the gauge, which calculates the thickness of the specimen. When the thickness is calculated it is displayed and transferred to the remote controller if the gauge is equipped with a serial, USB, or other type of port.

[0007] Typical ultrasonic thickness gauges operate in the "Pulse/Echo" mode, by timing precisely the reflection of the echo bounced back at normal incidence from the reflecting surface such as the bond interface. If the gauge is calibrated to the speed of sound in the test material then the thickness is determined by an internal calculation performed by the gauge processor using the following relationship [Ref. 1]:

$$Thickness = V\ (t-t_o)/2$$

where: V – the velocity of sound in the material,

t – the measured transit time of sound pulse,

t_o– the zero offset factor (to correct for transducer internal delay, cable delay, and other fixed delays).

[0008] A typical gauge can measure thickness in three modes. Mode 1 is used with contact transducers when the transducer is directly coupled to the surface of the specimen. In this mode, the transit time is measured between a main bang MB pulse and a first returning echo. This method is simplest and it is frequently used for manual thickness measurements when the specimen is relatively thick, and only a few thickness data points are required to collect. Modes 2 and 3 are used with delay line, or immersion, transducers for the specimens of any, but preferably small or moderate, thickness when improved measurement accuracy is required. In Mode 2, the transit time is measured between the front surface and the first backwall (or bond interface) echoes, while in Mode 3 the transit time is usually measured between two consecutive echoes following the front surface echo. It is important to know that Mode 2 is preferred for materials with a higher sound attenuation, such as copper, cobalt, tantalum, or WTi while Mode 3 (which is most

accurate among all three modes) is preferred for low attenuated materials such as aluminum, titanium, or tungsten.

[0009] Implementation of Modes 1, 2, or 3, when the transducer (with or without delay line) is directly coupled to a target surface, is limited to scratch resistant materials, since only a droplet of water can be used for target coupling. As seen frequently in practice, a thin layer of water does not provide an adequate protection for target surface, particularly of soft materials such as aluminum or copper, from scratching. Another drawback of direct contact coupling is that manual operation depends on operator hands-on experience. A still further drawback of direct contact coupling is the occasional difficulty in finding a region of the target with a minimal thickness. However, the direct contact coupling has one important advantage, namely, compactness and mobility, that makes it a preferred technique for use in-situ when the part remains attached to the chuck of the machining tool. This simplifies testing and reduces the overall test time.

[0010] Non-contact immersion Modes 2 and 3 are designed to overcome limitations of contact methods providing non-scratching, accurate, and automated methods of testing. Immersion thickness testing can be done in two ways. It can be done by submerging the entire target assembly and the transducer into a tank with de-ionized (DI) water where a stationary column of coupling water between target and transducer is formed. The advantage of this technique is the ability of using conventional C-Scan technology and equipment. The disadvantage of this technique is the relatively high cost since several steps are required to complete the test. Steps include removing the target from machining tool and placing it into a C-Scan tank for testing, then replacing the target back to the machining tool to complete machining. After-test machining is also required, at least as a refinishing measure, to remove the hydro-oxidation caused by extended exposure of the target surface to the water. Aluminum and copper-made targets are among of most susceptible to hydro-oxidation.

[0011] The other way of using immersion testing is a bubbler technique (FIG. 1) [Ref.2]. The bubbler technique may provide a definite advantage for target thickness measurement compared to all previously discussed methods. The

sound beam, in this case, propagates through a column of flowing water, which impinges into the target surface. As a result, the water exposure and subsequently hydro-oxidation can be minimized drastically by reducing the size of the water contact area and exposure time. This can be achieved by decreasing the diameter of the water contact area and by bringing this area into a continuous moving contact all over the target surface. However, there is a limitation frequently imposed by conventional bubbler techniques. The limitation is a lack of spatial resolution. Conventional conveyor-based bubbler techniques, for example, used in metal rolling mills and etc, acquire thickness data at certain space intervals usually pre-defined by conveyor speed and data acquisition rate. For high conveyor speed applications a plurality of positions from where the thickness data are sampled, can be separated be lengthy intervals that pose a danger of missing the positions with a critical minimum thickness. This is absolutely not acceptable for sputtering target applications. The region of a target with a minimum thickness should always be detected since the minimum thickness is among the most critically controlled target geometrical parameters, which governs pass/fail criterion of the target. Conventional bubbler techniques have another drawback, which may interfere with test remote operation. This additional drawback is the possibility of interruption in the data acquisition process due to occasional discontinuity in the water flow, especially for small bubbler apertures when a chain of air bubbles is formed in the water supply stream.

[0012] Therefore, there is still a need in the art for precision, low cost, non-contact, automated, ultrasonic target thickness measurement technique performed in-situ inside a machining tool.

SUMMARY OF THE INVENTION

[0013] This need and others are addressed by the bubbler-based, automated, non-contact ultrasonic thickness measurement method comprising the steps of sequentially irradiating rotating sputtering targets with sonic energy at normal incidence at a plurality of positions on the surface of the target; detecting echoes induced by the sonic energy and reflected from both surfaces of the target with a

data acquisition frequency not synchronized with rotational speed of the target; measuring sound transit time between two consecutive echoes and calculating thickness by multiplying known sound velocity of target material by one half of measured transit time of sound pulse, corrected for zero offset factor; sending every value of the thickness data as soon as it calculated to a remote controller; merging all values of thickness data points to form one sequential file of a statistically representative group of thickness values; analyzing this file of statistically representative group of thickness values to extract the value of target minimum thickness.

[0014] Unlike the prior art described in FIGA, the method of the present invention provides a target thickness measurement technique, which is always able to find and measure target minimum thickness. This is achieved by over-sampling of the target thickness data by multiple and repeated sampling from the same region of the target confined by a plurality of positions along the same circumferential path of constant radius formed by a number of consecutive revolutions. The over-sampling is achieved by irradiating the same region of the rotating target during more than one revolution using a stationary bubbler and a data acquisition frequency, which is not synchronized with the target RPM. In this case for every consecutive revolution a plurality of positions from where the data are collected does not repeat itself. Merging of all the thickness data points from each of the plurality of positions into one sequential file provides a statistically representative number of almost all-possible positions for a specific circumferential path. This improves the probability of finding and measuring the target minimum thickness.

[0015] It is another object of the invention to provide the apparatus for automated non-contact in-situ target thickness measurements. The apparatus consists of an enclosed immersion bubbler with outside shape and dimensions matching the shape and dimensions of the cutting tool holder of the machining tool; a bubbler body with a water extracting nozzle; a transducer, mounted inside the bubbler axially symmetrical with a nozzle at a distance from its opening; an electric cable connecting the transducer with a thickness gauge which, in turn, is remotely connected to a controller; a water supply line connecting the bubbler with a DI

water source using at least two valves, connected in series, one for on/off operation and the second for precision water flow tuning.

[0016] The method, as described, can be used to measure the thickness of any planar, hollow cathode or other type of sputtering targets when the sound energy is confined into a beam directed nearly perpendicular to the tangent to both surfaces at the beam entrance positions. This method can also be used for non-target applications such as aircraft engines, or for targets of varying shapes (FIG. 4).

[0017] These and other features and advantages of this invention are described in, or are apparent from, the following detailed description of various exemplary embodiments of the systems and methods according to this invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Various exemplary embodiments of the systems and methods of this invention will be described in detail with reference to the following figures, wherein:

[0019] Figure 1 illustrates a schematic representation of a bubbler technique (prior art);

[0020] Figure 2 illustrates a schematic diagram of an exemplary method and apparatus according to the invention;

[0021] Figure 3 illustrates a detailed schematic diagram of the method and apparatus of the invention; and

[0022] Figure 4 illustrates other schematic diagrams of examples of apparatii able to be measured according to the systems and methods of the invention.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0023] Turning to FIG. 2 and 3, there may be seen schematic diagrams illustrating the method of instant invention. In accordance with this method, a test target specimen 20 of a bonded target assembly having a planar front surface 24 and non-flat but smooth bonded surface 26 is mounted into chuck 28 of a

machining tool. The machining tool rotates the specimen 20 axially symmetrically. Ultrasonic transducer 36 with a flat surface is mounted inside a bubbler 32. The transducer 36 is positioned axially symmetrical with a nozzle 34 at some distance from nozzle opening. The bubbler 32 is placed near the front surface 24 of specimen 20. The transducer 36 irradiates the front surface 24 of the test specimen 20 with a single, short-duration, megahertz frequency range ultrasonic pulse 38 propagating through columns 76 and 60 of de-ionized (DI) water which connect the face of transducer 36 with the front surface 24 (Fig.2, 3). Part of ultrasonic pulse 38 in the form of an echo 44, is reflected back to the transducer 36 from the front surface 24. The other part 40 of the pulse 38 propagates through the body of the specimen 20 at nearly normal incidence to the tangent of smooth bonded surface 26, and is reflected back to the transducer in the form of echo 50. The transducer 36 thus receives echoes 44 and 50, converts them into electric signals 52 and 56, and sends them along the cable 58 to the gauge 59 for processing. By measuring the difference in time it takes signal 52 from the first echo 44 to occur versus the signal 56 from the second echo 50 to occur, one can approximate the thickness of the specimen 20. Though the target specimen 20 of Figure 1 is comprised of a generally planar front surface 24, the thickness of specimens having other shapes, such as U-shaped hollow cathode sputter targets having convex or concave front surfaces bonded to a backing surface, could also be measured using the systems and methods described herein by reflecting echoes from the front surface and front surface/bonded surface interface to the transducer as described above.

[0024] As illustrated in Fig. 2 and 3, column 60 of flowing DI water is used to provide a path for ultrasonic pulse 38, and resulting echoes 44 and 50. The nozzle 34 with the opening 62 creates the column 60 of DI water with a diameter in the range of 0.187 in (4.75 mm). The opening 62 is placed most-preferably at the distance of 0.020 in - 0.040 in (0.5 mm - 1.00 mm) from the surface 24 of the specimen 20. The DI water to the bubbler 32 is supplied through the inlet 70 with diameter of 0.157 in (4 mm). The inlet 70 is positioned behind the face of transducer 36. The length of water column 76 inside the bubbler between transducer 36 and the opening 62 is chosen most preferably in the range of 1.00-in.

(25.4 mm). This length prevents detection of second echo 46 from the front surface 24 before arrival of echoes 44 and 50. The nozzle 34 has a removable lid 80 (not shown) which is used to protect transducer 36 and bubbler 32 interior from contamination or damage by flying chips and cutting fluid, in the case when the bubbler is not in use. The rear part 84 of the bubbler 32 is permanently sealed to protect transducer electric connector 86.

[0025] The bubbler 32 is mounted on a turret 90 in the position 92 originally designated for the cutting tool. To provide the water to the bubbler 32 a plastic clear hose 94 is connected to inlet 70. The hose 94 is connected in series with two valves 96, 98. Valve 98 is used for on/off operation while the valve 96 is used for fine-tuning of water flow. The tuning of water flow is necessary to form a preferably continuous laminar flow which is free from isolated or chained air bubbles all along the water supply system including hose 94, and columns 76 and 60.

[0026] The presently preferred transducer 34 is sold by Krautkramer-AGFA Co under the designation 113-126-340. This is an IPS style immersion non-focused transducer with 0.250 in (6.35-mm) element size, and 10 MHz peak frequency. The transducer 34 is electrically connected to presently preferred thickness gauge 59, sold by Panametrics under the designation 25DL. The gauge 59, which has continuous thickness data output, is connected through RS-232 port with a remote PC controller 110. Controller 110 is programmed in a conventional manner to initiate the data acquisition event, to collect a series of consecutive thickness data points for several consecutive revolutions of the specimen 20, and finally to stop the data acquisition. Furthermore, controller 110 is programmed to process the data statistically to find a minimum thickness value. It is also programmed to display the minimum value and to send it to the database if required.

[0027] The method works as follows. At first, the bubbler 32 with removed lid is moved towards a measurement position. The repositioning can be done manually or automatically. If CNC is used then the bubbler 32 mounted on turret 90 is programmatically moved to a pre-programmed X-Y position. This X-Y position is chosen to match a target position with the radius of the deepest sputter

erosion (sputter track area). The X-Y positioning is followed by positioning along the Z axis that brings the bubbler nozzle opening 62 closer to the target surface 24 with a gap preferably in the range of 0.020 - 0.040 in (0.5 mm - 1.00 mm). During the next step the target 20 is brought into rotation with a rotational speed preferably in the range of 1-100 RPM. Next, the water supply valve 98 is opened. The flow of the water is adjusted by the valve 96 to eliminate the turbulence and air bubble formation. During the next step, the PC controller 110 sends the command to the gauge 59 to start the data acquisition. The gauge acquisition rate (or frequency) is set preferably to the range of 1-50 acquisitions per second. It should be noted that the gauge should be preprogrammed and calibrated before the test using known material sound velocity and thickness ranges. The program can be stored internally in the gauge 59 memory or remotely in the controller 110 memory and should be recalled for the test. The target thickness is determined during every data acquisition event for every position on the target surface. The thickness value is sent automatically to remote controller 110 for storage and processing. When the pre-programmed number of thickness data points are collected preferably in the range of 100 - 10,000 thickness data points collected, the controller 110 sends commands to the gauge 59 to stop the data acquisition. During the next step, controller 110 evaluates the collected data for the minimum thickness value or other value of interest. It should be emphasized that the data acquisition frequency should be chosen substantially different from the target RPM. In this case, a plurality of positions on the target surface from where the thickness data are collected would be substantially different for every consecutive revolution of the target. Merging of all these positions for all consecutive revolutions creates a file representing a surface ring formed by a plurality of repeatedly superimposed positions constituting a continuous area projected on a sputter track region.

[0028] Of course, while the exemplary embodiments of the invention described above comprise measuring the thickness of relatively flat specimens 20 bonded to smooth bonding surfaces 26, the measurement system and methods described could as well be used to determine the thickness of non-flat specimens

such as U-shaped hollow cathode sputter targets, or other shaped specimens as shown in Figure 4, for example, as is evident to the artisan.

[0029] While the method herein described, and the form of apparatus for carrying this method into effect, constitutes a preferred embodiment of this invention, it is to be understood that the invention is not limited to this precise method and form of apparatus, and that changes may be made in either without departing from the scope of the invention, which is defined in the appended claims.

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I/WE CLAIM:

1.   A method of non-contact ultrasonic thickness measurement of sputtering targets having a front surface and front surface/bonded surface interface comprising the steps of:

(a)   securing the target to a rotating holder;

(b)   sequentially irradiating the front surface with pulses of sonic energy at a plurality of positions at normal incidence to a tangent line at a plurality of positions on the front surface, at least one of the pulses propagating through the front surface to the front surface/bonded surface interface;

(c)   detecting consecutive echoes induced by said pulses of sonic energy, the echoes being reflected from the front surface and from the front surface/bonded surface interface, respectively;

(d)   converting the front surface echoes and the front surface/bonded surface interface echoes into corresponding electric signals;

(e)   determining transit time of the sound path between the front surface echoes and the front surface/bonded surface echoes based on the corresponding electric signals;

(f) determining thickness data of the target by multiplying known sound velocity of the target material by one half of measured transit time, corrected for a zero offset factor;

(g) electronically sending the determined thickness data to a remote controller;

(h)   collecting thickness data for a plurality of positions on the target;

(i)   analyzing the collected data and extracting the value for the minimum thickness of the target.

2.   The method as recited in claim 1 wherein said sputter target is attached to a backing plate by means of bonding.

3.   The method as recited in claim 1 wherein said sputter target is bonded to a backing plate to form a target assembly

4.   The method as recited in claim 1 wherein said sputter target remains attached to a rotating machining tool chuck or other specimen holder and is rotated axially symmetrically during the entire thickness measurement process.

5.   The method as recited in claim 1 wherein the sonic energy propagating across the bonding surface/front surface interface is nearly normal incidence to the front surface/bonded surface interface.

6.   The method as recited in claim 1 wherein said sonic energy is generated as a pulse by an ultrasonic transducer enclosed in an immersion bubbler axially symmetrically opposed to the front surface of the target.

7.   The method as recited in claim 1 wherein step (b) includes coupling the rotating target with an ultrasonic transducer by a column of a non-turbulent bubble-free stream of water to the front surface of the target.

8.   The method as recited in claim 1 wherein step (b) includes irradiating the target with sonic energy passing through a water column generated by an immersion bubbler.

9.   The method as recited in claim 1 wherein step (b) includes impinging the target with sonic energy at substantially normal incidence to the front surface.

10.   The method as recited in claim 1 wherein step (b) includes impinging the target with sonic energy in a form of short duration, MHz frequency ultrasound pulse.

11.   The method as recited in claim 1 wherein the echoes are detected with a data acquisition frequency substantially non-synchronized with the RPM (revolution per minute) of the rotating target.

12.   The method as recited in claim 1 wherein the echoes detected are returned at normal incidence to the surface of said transducer.

13.   The method as recited in claim 1, wherein said echoes are detected from a plurality of positions for more than one revolution of target under rotation.

14.   The method as recited in claim 1, wherein said the calculated thickness data sent for a plurality of positions is collected for more than one revolution of the target.

15.   The method as recited in claim 1, wherein at least 100 measurement calculations based on the thickness data collected is performed.

16.   The method as recited in claim 1, wherein all the data points of thickness data are merged into one sequential file.

17.   The method as recited in claim 1, wherein irradiating said sputtering target with pulsed sonic energy occurs additionally along a circumferential path of constant radius constituted by a plurality of all possible positions on the target front

surface encompassing the ring with the area projected into the region of deepest sputter erosion.

18. The method as recited in claim 18 wherein said a plurality of all possible positions is formed by more than one revolution of the target against a stationary source of sonic energy.

19. The method as recited in claim 1, wherein the sputter target is a hollow cathode sputter target having one of a convex and a concave front surface.

20. Apparatus for measuring thickness of a sputtering target bonded into an assembly comprising:

a transducer for sequentially irradiating a sputtering target with sonic energy and
detecting echoes induced by said sonic energy;

an enclosed immersion bubbler, encompassing the transducer, mounted axially
symmetrical with a nozzle of said bubbler at normal incidence to a surface of the target;

a thickness gauge electrically connected to said transducer and programmed to
measure a sound transit time between two consecutive echoes, and programmed to calculate the specimen thickness, based on known sound velocity, transit time, and zero offset factor;

a controller electrically connected to the thickness gauge and programmed:
(a) to send a trigger command to start the data acquisition;

(b) to receive and calculate values of the thickness as soon as thickness data collection is completed;

(c) to merge each calculated thickness value into one sequential file;

(d) to send a trigger command to stop the data acquisition;

(e) to analyze the data, determine and display the value for the minimum target thickness.

21. The apparatus as recited in claim 20 wherein said bubbler is physically spaced from the target front surface so as to not contact physically the front surface of the target.

22. The apparatus as recited in claim 20 wherein said bubbler includes a nozzle having an opening providing fully transparent transmission of sound energy to and from the transducer.

23. The apparatus as recited in claim 22 wherein said transducer is positioned inside the bubbler a distance from the nozzle opening to prevent receipt of an interfering echo prior to receipt of consecutive echoes from the front surface of the target and from a front surface/bonded surface interface of the target, respectively.

020324-241P2-USP1

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ABSTRACT

[0030] A method and apparatus for ultra-sonically measuring the thickness of sputter targets of varying shapes. An immersion bubble and transducer provide pulses to a front surface and a front surface/bonded surface interface of a target. The pulses generate reflected echoes that are converted to electric signals. By measuring the difference in time that the electric signals occur the thickness of the target may be approximated to identify whether the thickness of the target is appropriate for use.
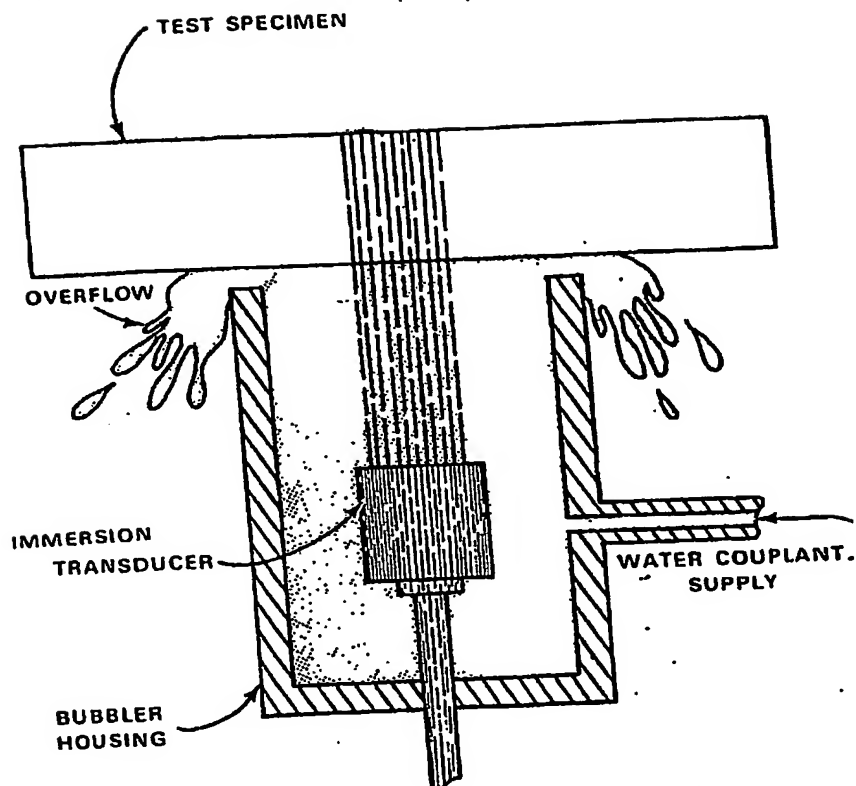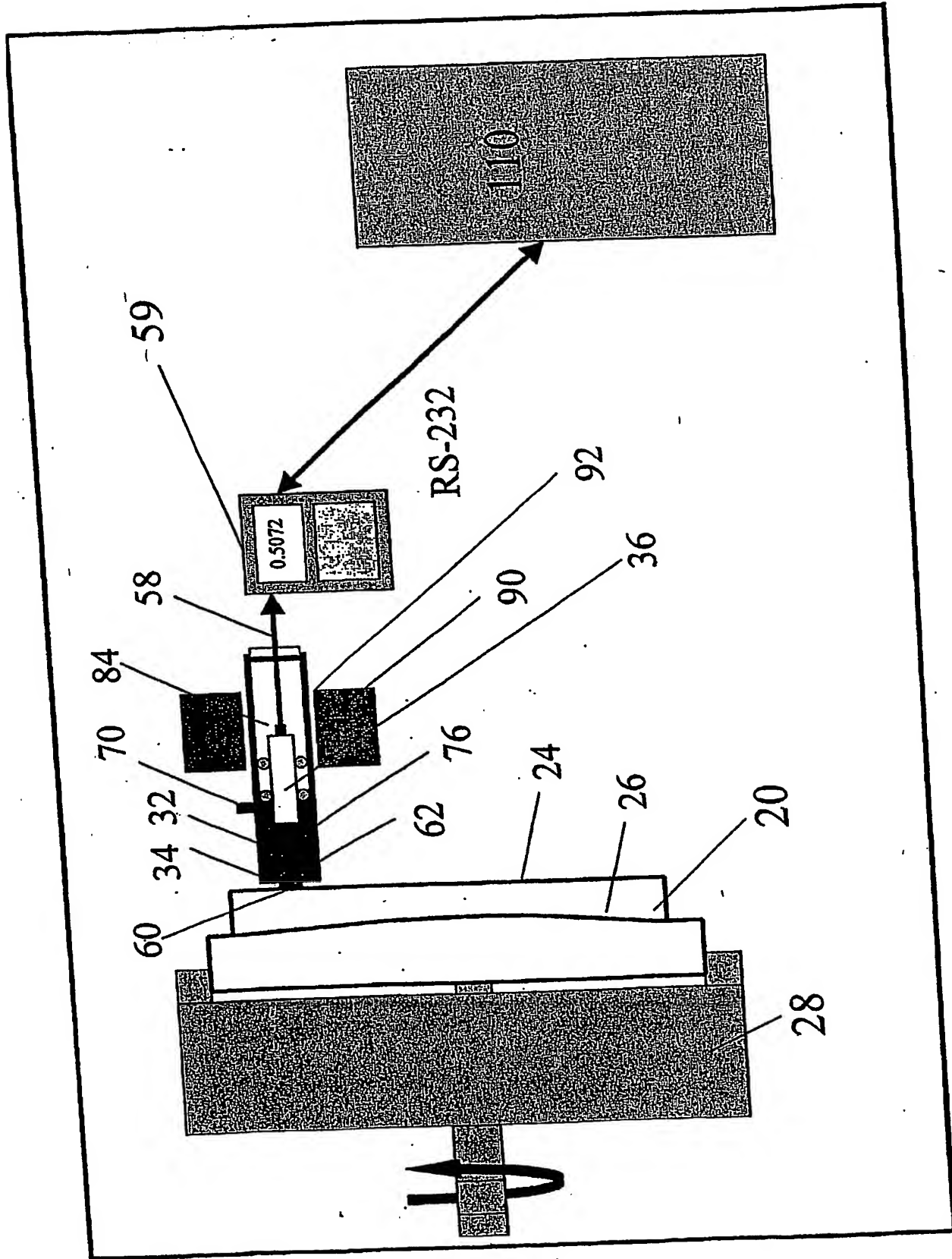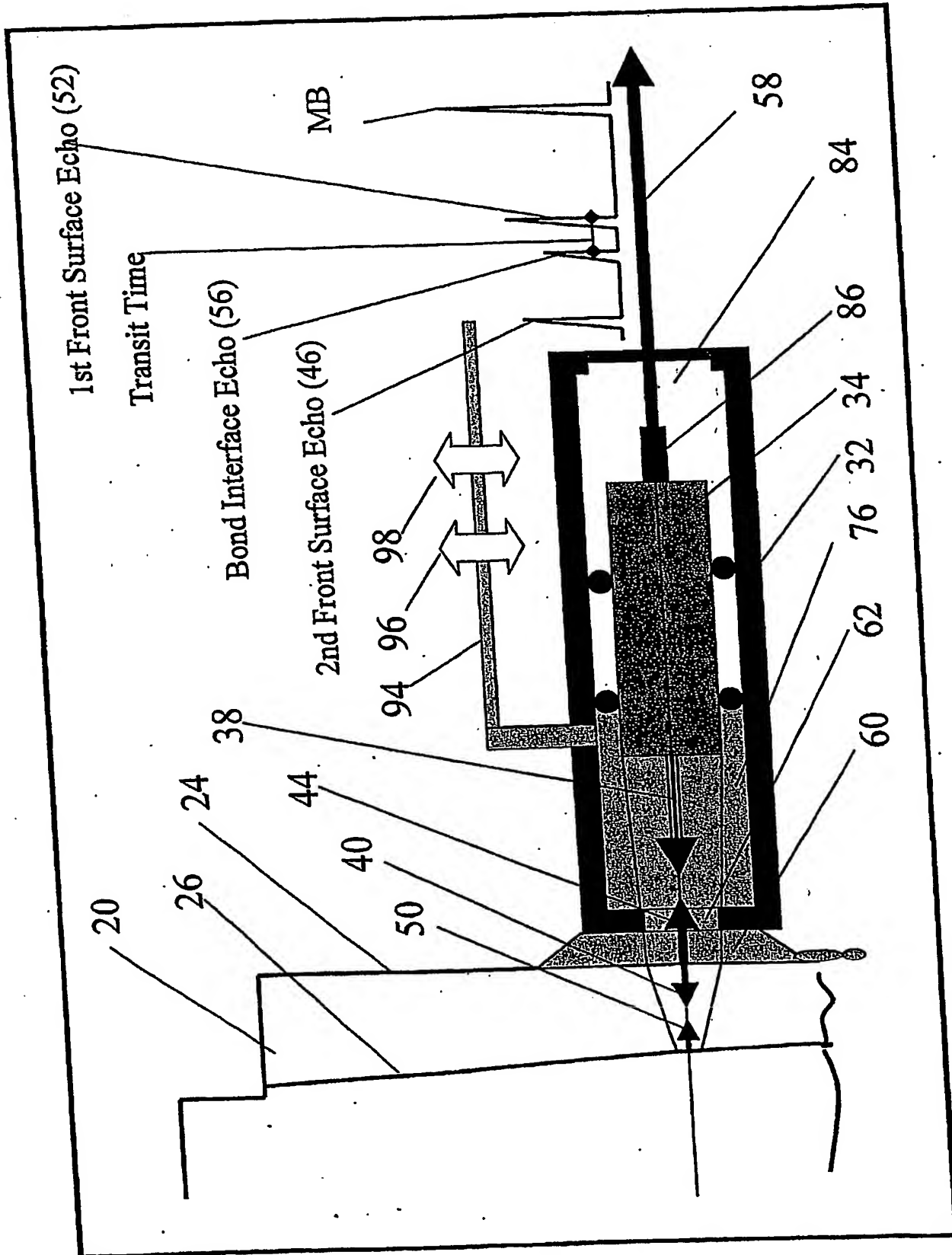
TEST SPECIMEN

OVERFLOW
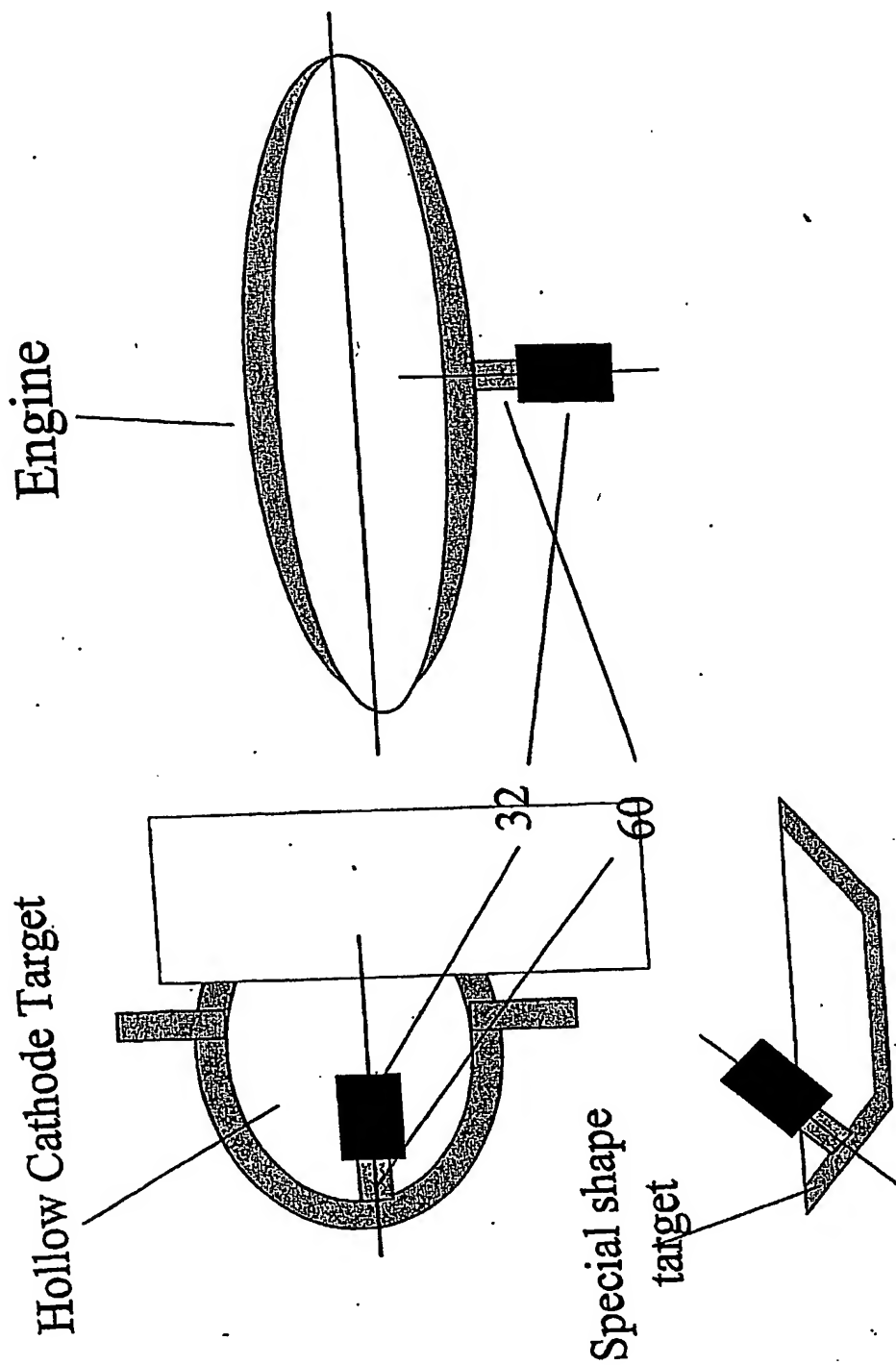
IMMERSION
TRANSDUCER

WATER COUPLANT.
SUPPLY

BUBBLER
HOUSING

FIG. 1

RS-232

FIG. 2

1st Front Surface Echo (52)

Transit Time

Bond Interface Echo (56)

2nd Front Surface Echo (46)

MB

58

84

86

34

32

76

62

60

98

96

94

38

24

26

44

40

50

20

26

FIG. 3

Engine

Hollow Cathode Target

32

60

Special shape
target

FIG. 4